Modeling the Impact of a Sex Pheromone/Kairomone Attracticide for Management of Codling Moth (*Cydia pomonella)*

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Abstract

The pear-derived volatile, ethyl (2E, 4Z)-2,4-decadienoate is a potent, stable, and selective bisexual kairomone for codling moth, *Cydia pomonella* L. Its discovery creates an unique opportunity to develop monitoring and control tactics targeted for both male and female moths. Here we present a population model that compares the relative effectiveness of a male-only versus a bisexual attracticide. The model tracks daily changes in the population densities of pupae, males, and mated and virgin females using daily survival rates, and natural and insecticide-related mortality for eggs and larvae. The use of sex pheromones for mating disruption is included as a scalar variable affecting mating success. Mating is also influenced by the level of competition between virgin females and the insecticide-laced pheromone point sources (determined by their density and potency). The attractiveness of the kairomone lure is determined by the density and relative attractiveness of individual fruits within the cropping system. The potency (attractiveness and lethality) of the attracticide point sources decline at a constant rate over time. Our modelling results demonstrate that the use of a female attractant greatly improves the effectiveness of the "attract and kill" technique. Our model output is compared with field data collected from apple plots treated with mating disruption and a grid of pheromone/kairomone-baited insecticide-treated stations during 2001. The influence of the seasonal attractiveness of ethyl (2E, 4Z)-2,4-decadienoate for codling moth within walnut, pear, and apple orchard the success of the "attract and kill" approach is discussed.

INTRODUCTION

Management of codling moth, *Cydia pomonella* L. with its sex pheromone, codlemone, has been successfully adopted in the western United States and parts of Europe (Thomson et al., 1999). The most widely used approach to date has been the application of 500 – 1,000 plastic dispensers per hectare to disorient moth sexual communication. An alternative behavioural approach for managing codling moth has been the development of pheromone paste formulations containing an insecticidal agent (Charmillot et al., 2000; Lösel et al., 2000). This "attract and kill" approach has been successful in orchards where communication disruption is difficult to achieve due to small orchard size, uneven topography, or high moth immigration (Charmillot et al. 2000).

Potting et al. (2000) built a simulation model to study the factors affecting the efficacy of a pheromone-based attracticide for codling moth. This model considered the competition between virgin females and pheromone point sources in luring male moths. Both the potency of the drops and their residual characteristics were important factors affecting the success of this approach. Their model showed that the insecticide-laced pheromone droplets needed to be applied at a density 3 to 5-fold higher than the female moth density. These data suggest that pest species such as codling moth that occur at low population densities, are especially amenable to control with "attract and kill" approaches. However, the propensity of codling moth males to mate with more than a single female during their lifespan (Howell 1991) reduces the potential of this technique. For example, a successful “attract and kill” formulation that might kill 95% of the males would only cause a 75 - 85% reduction in the percentage of mated females if males mate with 3 – 5 females. The development of a tactic that could attract and kill female moths and especially virgin females would likely be effective at a much lower level of efficiency. However, early efforts to manage codling moth utilizing devices attractive to both sexes (light traps or bait buckets) were both ineffective and cumbersome (Worthley and Nicholas, 1937).

The pear ester, ethyl (2E, 4Z)-2,4-decadienoate, has a potent and stable attractant for both male and female codling moths (virgin and mated) and has opened up the possibility of developing a more effective attracticide strategy (Light et al. 2001). This ester is a major component of ripe pear and has been detected at low levels in ripe apple. However, ethyl (2E, 4Z)-2,4-decadienoate has not been found in immature pome fruit or in walnut (Light et al., 2001). Similarly, the attractiveness of this compound for codling moth varies among crops (high all season in walnut [similar to a sex pheromone lure], low all season in pear [declines from ¼ to 1/10 a pheromone lure], and declines from high to low in apple during the season [declines from equivalent to 1/7 a pheromone lure) (Light et al., 2001).

Initial development of ethyl (2E, 4Z)-2,4-decadienoate in an “attract and kill” paste formulation was slowed when we observed that codling moth adults typically approached only within 10 cm of the attractant and rarely touch paste droplets. Alternately, we have pursued the idea of using an array of insecticide-treated bait stations baited with grey septa lures containing ethyl (2E, 4Z)-2,4-decadienoate and/or codlemone.

Potting et al. (2001) modelled the use of a hypothetical insecticide-laced kairomone attractant alone and in combination with a pheromone lure. The kairomone was arbitrarily set to 1/20 and ½ the attractiveness of the combined fruit on an entire tree (200 per tree) and the addition of the kairomone only marginally (< 10%) increased the performance of the pheromone lure and kill strategy alone. Increasing the kairomone attractiveness to 1.5 tree units generated a 40% reduction in fruit injury. Unfortunately, the relative attractiveness of lures loaded with ethyl (2E, 4Z)-2,4-decadienoate compared to individual intact pome fruits is unknown.

Here we report modelling studies conducted using a modified version of this model to evaluate parameters affecting a male + female versus a male-only attracticide. The model was used to explore the use of a kairomone lure exhibiting a broader range of attractiveness than runs conducted by Potting and Knight (2001). The model was also adjusted to fit the use of bait stations in combination with mating disruption and supplemental applications of horticultural oil. These data were then compared with mid-season field results collected from replicated apple plots in 2001.

MATERIALS AND METHODS

Model Outline

The model is divided into three sections: cropping system, pest biology, and the semiochemical-based control inputs (Fig. 1). The cropping system includes the tree and fruit density that serve as the basis for the determination of the economic threshold level and the competition between the kairomone lure and moths. Pest input-parameters include pupal density and daily changes in adult, egg and larval density influenced by natural factors and the application of insecticides. Key model state variables include male moth density, virgin female density and mated female density. The cumulative number of mated females determines, in combination with the crop system parameters, the level of expected damage (i.e. larval infested apples). The number of virgin calling (i.e. pheromone releasing) females determines the level of competition with the pheromone attracticide sources. Parameters of the attracticide application include the droplet density and droplet potency. Droplet potency is a combination of relative attractiveness of the pheromone or kairomone component and the relative knockdown potential of the insecticide component. Droplet potency decreases with exposure time to ambient weather conditions (default value: 0.025 day^{-1}). Potting et al. (2000) set the maximum attractiveness of the synthetic pheromone droplet at a nominal value of 1, which equals the attraction towards a calling female. The kairomone potency is related to crop load and a relative attractiveness index compared with an individual fruit. The kairomone is attractive to 50% males, 25% mated females, and 25% virgin females. A more detailed description of the algorithms used to determine the probability of mating and the durability of the attracticide are provided in Potting et al. (2000). In the modified model the effect of mating disruption was modelled by a mating disruption factor influencing the daily rate of mating. This factor was assumed to be constant throughout the season.

Model Calibration

Several model parameters were adjusted to fit the field data. The model was set to 500 trees per hectare and 150 fruits per tree to reflect actual conditions in the apple orchards studied. The overwintering population density was set to 14,000 pupae per hectare or 28 pupae per tree. The orchards used in this field study suffered > 20% fruit injury at harvest during the previous season and the overwintering population was likely very high. Egg survivorship in the model was reduced 60% in the plots treated with horticultural oil based on previous field trial results evaluating the efficacy of these materials (A.L.K., unpublished data). Natural egg and adult daily survivorship was increased from 0.75 to 0.80. The relative attractiveness of the pheromone lure in a bait station versus a calling virgin female was set at 40.0 based on extensive data collected from 1994-1999 showing that virgin female-baited traps catch 40-times fewer male codling moths than synthetic pheromone-baited traps in apple orchards treated with sex pheromone dispensers for mating disruption (A.L.K., unpublished data). The effect of deploying sex pheromone dispensers on mating success was set at 75% disruption. Data collected from pheromone-treated orchards over the past six years have shown that the proportion of mated codling moth females is only reduced 50%, but due to a delay in mating, the reproductive potential of mated females is reduced another 50% (Knight, 1996; Knight, 2000). Thus the combined effect is equivalent to a 75% reduction in the population growth.

Field Trial Validation

Four replicated 0.6 ha plots were established in apple orchards treated with sex pheromone dispensers for mating disruption. Bait stations were spaced 15 m apart and hung in the upper third of the canopy. Bait stations consisted of a corrugated plastic delta trap (30 x 30 cm) with its upper surfaces (inside and out) coated with 0.18 mg / cm^2 of formulated esfenvalerate. Kairomone lures were placed in all traps and 40% of the stations also received a pheromone lure (60 traps per hectare baited with the pear ester and 25 traps were baited with both the ester and sex pheromone). Two of the four plots were also treated with three applications of 1.0% horticultural oil timed 7 to 10 days apart for control of codling moth eggs. Fruit were sampled for codling moth injury in each plot in late June and in similar plots treated only with sex pheromones for mating disruption and in plots left untreated.

RESULTS

An attracticide that kills both sexes of moths is clearly more effective in reducing fruit injury by codling moth (Fig. 2). Under the given field scenario of a high overwintering population density we found that > 70% of the adults would need to be killed to result in < 1.0% fruit injury. In comparison, a similar level of fruit injury would require 95 – 99% moth kill with a male-only attracticide. The model very closely predicted the level of fruit injury in the untreated plots and in plots treated only with sex pheromone dispensers for mating disruption (Table 1). Levels of fruit injury in plots treated with a combination of mating disruption and the attracticide declined from the borders to the center of the treated plots. The model predicted that the kairomone lure would need to be equivalent to the attractiveness of 10 – 20 tree units to achieve levels of fruit injury reductions similar to those observed in our field plots (Table 1).

DISCUSSION

Potting et al. (2000) assessed the role of both abiotic factors (attractant release characteristics, spacing and durability of the attracticide formulation) and biotic factors such as the population biology and behavioural characteristics of the pest species in the control efficacy of a pheromone-based attracticide. They found that a proper matching of the attracticide point source density with the moth density was an important factor determining reliable population control as well as a proper timing of the attracticide application due to the degradability rate of the formulation in ambient weather conditions. Potting and Knight (2001) included the use of a plant host-derived kairomone to improve the effectiveness of the system. Here we have adjusted this model further to examine the potential integration of several control tactics: mating disruption, attracticide, and supplemental insecticide sprays. The process of parameter estimation for this new model has allowed us to investigate the efficacy of variable management options (density of bait stations, lure potency, and moth density) that will aid the future development and optimisation of this technology.

Seasonal changes in the attractiveness of ethyl (2E, 4Z)-2,4-decadienoate occur in both apple and pear orchards (Light et al. 2001). Within apple orchards this kairomone becomes less attractive relative to codlemone beginning in June and this lower level of attractiveness during the second and third moth flight may seriously limit its utility in this crop. In contrast, the season-long high level of attractiveness reported in walnut may allow this approach to be successful in this important crop.

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Tables

Table 1. A comparison of the model's output with mid-season fruit injury data collected from apple plots, June 2001.

Relative kairomone attractiveness (# tree equivalents)	Untreated	Mating disruption + attracticide	Mating disruption + attracticide + oil
0[a]	74.7 (75.0)	23.3 (25.0)	9.3 (6.0)
1	----	13.2	5.3
10	----	2.9	1.1
20	----	1.4	0.3
	Field data: Plot edge	4.0	1.0
	Plot center	1.0	0.3

[a] Values in parentheses were sampled from replicated apple field plots not treated with the attracticide approach.

Figures

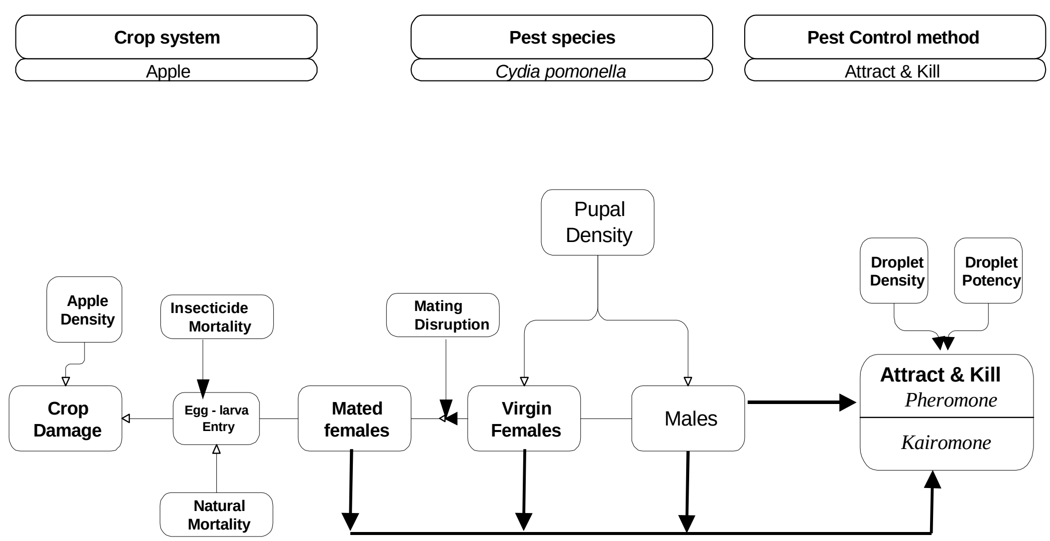

Fig. 1. Overview of the attract and kill model structure. The simulation model is constructed with parameters confined in: (1) Orchard environment (2) *Cydia pomonella* dynamics (3) Attracticide application characteristics. The attract and kill component is divided into a pheromone part affecting male behaviour and a kairomone part affecting males and females.

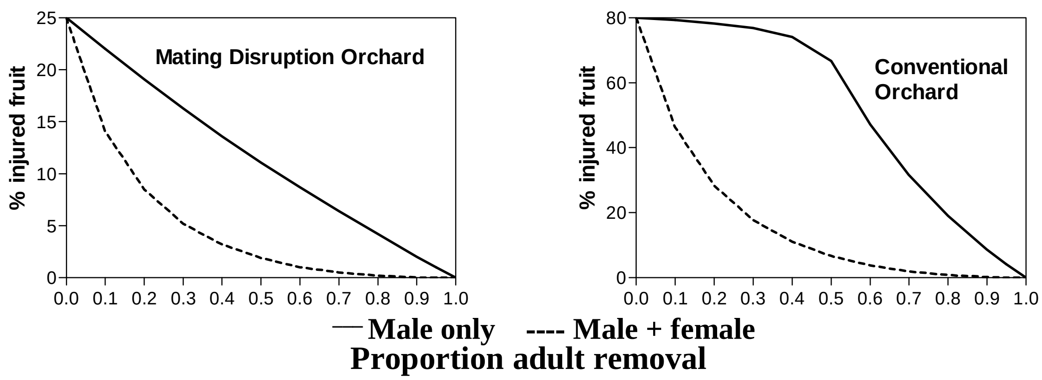

Fig. 2. Simulated levels of codling moth fruit injury determined by the proportion of adults removed under either a male-only or a male + female attracticide program in apple orchards treated either with sex pheromones for mating disruption or receiving no additional treatment.